A major purpose of the Technical Information Center is to provide the broadest dissemination possible of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state and local governments.

Although a small portion of this report is not reproducible, it is being made available to expedite the availability of information on the research discussed herein.

1

LA-UR -84-1938

NOTICE

PORTIONS OF THIS REPORT ARE ILLEGIBLE. It has been reproduced from the best available copy to permit the broadest possible availability.

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36.

TITLE: DESIGN, CONSTRUCTION, AND OPERATIONAL RESULTS OF AN 800-A, 10-KV HOT DECK AMPLIFIER

LA-UR--84-1938

DE84 014044

AUTHOR(S): William A. Reass

SUBMITTED TO: 1984 Sixteenth Power Modulator Symposium Conference Record June 1984.

Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

FORM NO 836 R4
ST NO 2629 5/81

DESIGN, CONSTRUCTION, AND OPERATIONAL RESULTS OF AN 800-A, 10-KV HOT DECK AMPLIFIER*

William A. Reass
Los Alamos National Laboratory
Los Alamos, New Mexico

ABSTRACT

This paper describes the electrical design, implementation, and operational results of a high fidelity (feedback regulated) 800 A, 10-kV hard tube, hot deck amplifier.

The amplifier can produce any linear waveform to 800-A for 30 ms and beyond (depending on main energy storage). The present use is to drive the vertical field (VF) control windings on ZT-40M, a toroidal reversed field pinch plasma physics experiment. Although our application requires only 10 kV (8 MW) of switching, anode voltage may be as high as 40 kV (32 MW).

The hot deck consists of a solid state driven, two stage, 200-kW tube amplifier driving four parallel ML8618 magnetically beamed output triodes. All power supplies, energy storage, and controls for the drivers are located in the hot deck. The solid state amplifiers and first tube stage are contained in an internal hot deck (hot deck within a hot deck) with control and error signals originating at ground potential via fiber optics. The error signal is generated by error and loop compensation amplifiers near the hot deck, with the voltage reference originating from the ZT-40M control room (fiber coupled). All fiber links are of the FM type with a dc to 1 MHz bandwidth that do not exhibit drift or require recalibration for cable length changes as occurs with AM links.

The hot deck amplifier components are contained in a 512 cubic foot (8×8×8) room. The deck itself requires 84 cubic feet (3×4×7). It is insulated (supported) from a unistrut framework below the deck. External to the amplifier room are the interlock controls, 480-V ac breakers, the main energy source and the charging controls.

The amplifier system exhibits a 60-kHz open loop bandwidth. The maximum effective closed loop bandwidth is slew rate limited to 10 kHz by the chosen anode voltage, vertical field coil inductance, and related shunt resistance. The output waveforms are "high fidelity" with no observable nonlinearities or overshoot with triangle or square wave test signals.

ELECTRICAL DESIGNS

Shown in Fig. 1 is the block diagram of the hot deck amplifier system. The energy source is provided from a 85-kJ, 10-kV capacitor bank in its present configuration. The hot deck receives all its power from low capacitance (H.V. insulated) filament and control transformers. Control signals such as the gate duration (on/off), error input, and interlock functions are coupled to the appropriate hardware via fiber optics. The 10-Ω output shunt resistor is required to limit the voltage transient on turn-off and provide an equal rate of current decay as that provided during turn-on. The 300-μH VF load coil consists of multiple windings wound toroidally around the ZT-40M machine. Output to the hot deck from the error and loop compensation amplifiers are the gate duration and error signal. The error signal is derived by comparing the VF coil current (from CVR), and a reference waveform.

The internal components of the hot deck are depicted in Fig. 2. The driver amplifiers consist of a solid state driven 3-1000 floating deck amplifier and a 3CX10000A7 cathode follower. This design is direct coupled and does not require power consuming level shifting techniques. To provide a high current, long pulse output without 60 cycle modulation, dc filament supplies are used. All static power for the drivers such as cooling, dc filament, interlocks, and solid state electronics are derived from the individual stages low capacitance (HV insulated) filament transformer. Bias and B+ capacitor banks provide the energy storage for the drivers. The output ML8618s are split into two pairs, with each pair receiving its filament power on a different phase. To prevent filament breakage on long square pulses, it is necessary to resistively ballast each filament terminal to the output (hot deck) common. With a single ended output connection; it may be that the magnetic field generated by the "unipolar" current through the filament rod, coupled with the proper ac filament current phase and the static dc field, is sufficient to cause filament failure.

To provide the necessary gating and voltage drive to the 3-1000, a conventional solid state amplifier is used (Fig. 3). Commercially available optic links used for the error signal have a 1-MHz bandwidth with a 5 volt maximum output and 40-db dynamic range. The 3-1000 amplifier is buffered by the 3CX10000A7 cathode follower that can provide in excess of 40-A peak current to the 8618 grids. To prevent high frequency oscillation, an L-R "DQ" network is used on all tube grids.

As significant coupling exists between the VF coil and plasma, the exact nature of the reflected impedance cannot be easily determined. The impedance would also change for different plasma conditions and currents. To ease system performance measurement, adjustment, and design, the error and loop compensation amplifiers are located at ground potential. To simplify compensation, a single dominant pole open loop gain was desired. Traces 1a thru 1d show the open loop performance into a resistive load. The top waveforms are the driving voltage (1 volt/division), the bottom traces the gated output (1000 V/div) waveform. These traces indicate a 60-kHz forward loop bandwidth with a single pole response. The gain slope at higher frequences did not show any peculiar changes.

Using the error and loop compensation amplifiers (Fig. 4) to measure loop characteristics, the loop was broken at TP1 and A4 given a gain of 1. The gain of A1 is chosen to give our system a transconductance of 200 A/volt. The solid state amplifier gain in the 3-1000 was then adjusted to give a loop gain of 1. The gain of A4 was then chosen to provide a forward loop gain of 26 db. The reference voltage waveform bandwidth is limited to about 7 kHz (.022 ufd & 1 kΩ) on A3 (error amp) due to relatively poor signal to noise ratios of the FM fiber links (~40 db). The limited reference bandwidth gives the appearance of a closed loop bandwidth of 7 kHz. With the VF coil used instead of a dummy load coil, trouble was experienced with closed loop amplifier stability (trace 2).

*Work performed under the auspices of the U.S. Department of Energy.

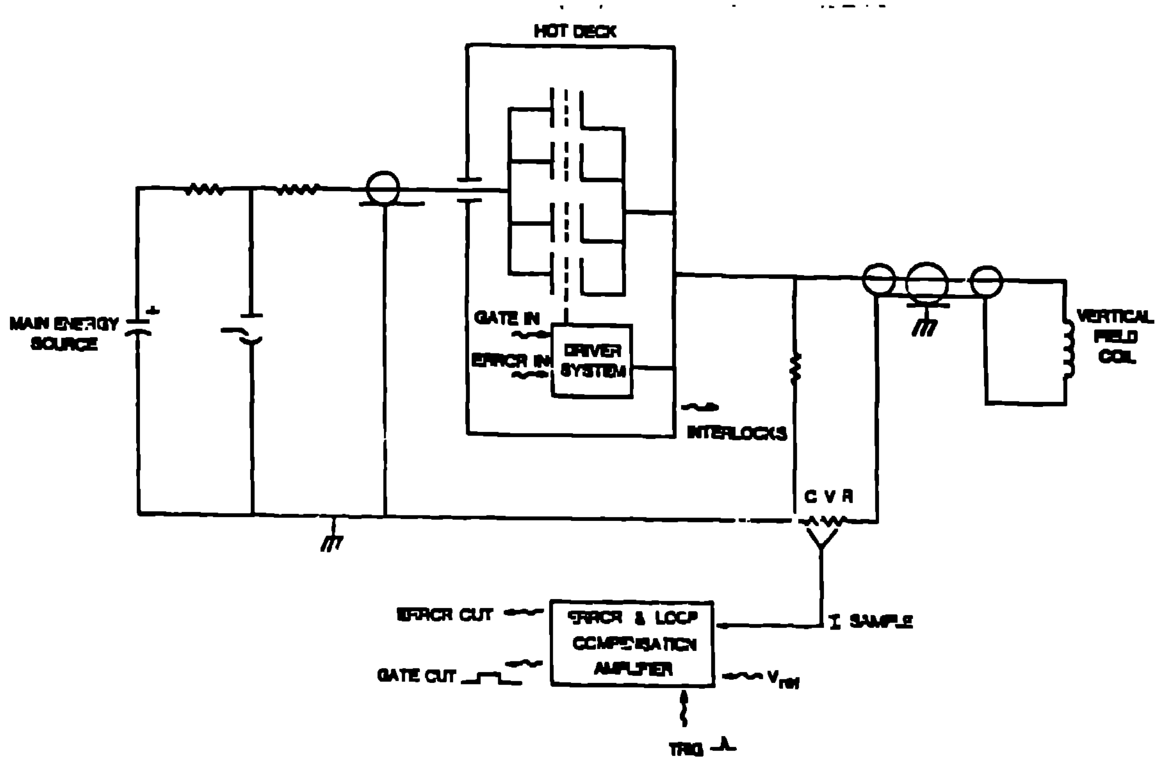


Figure 1. Block diagram of hot deck amplifier system.

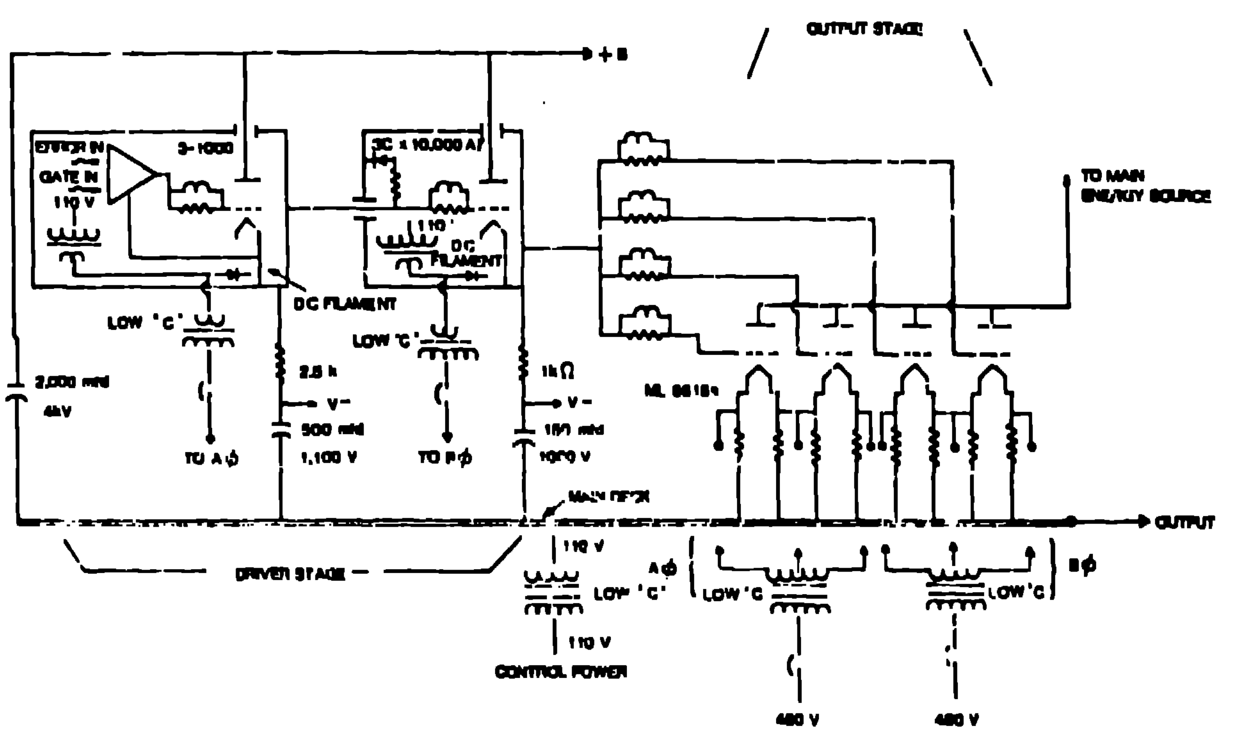
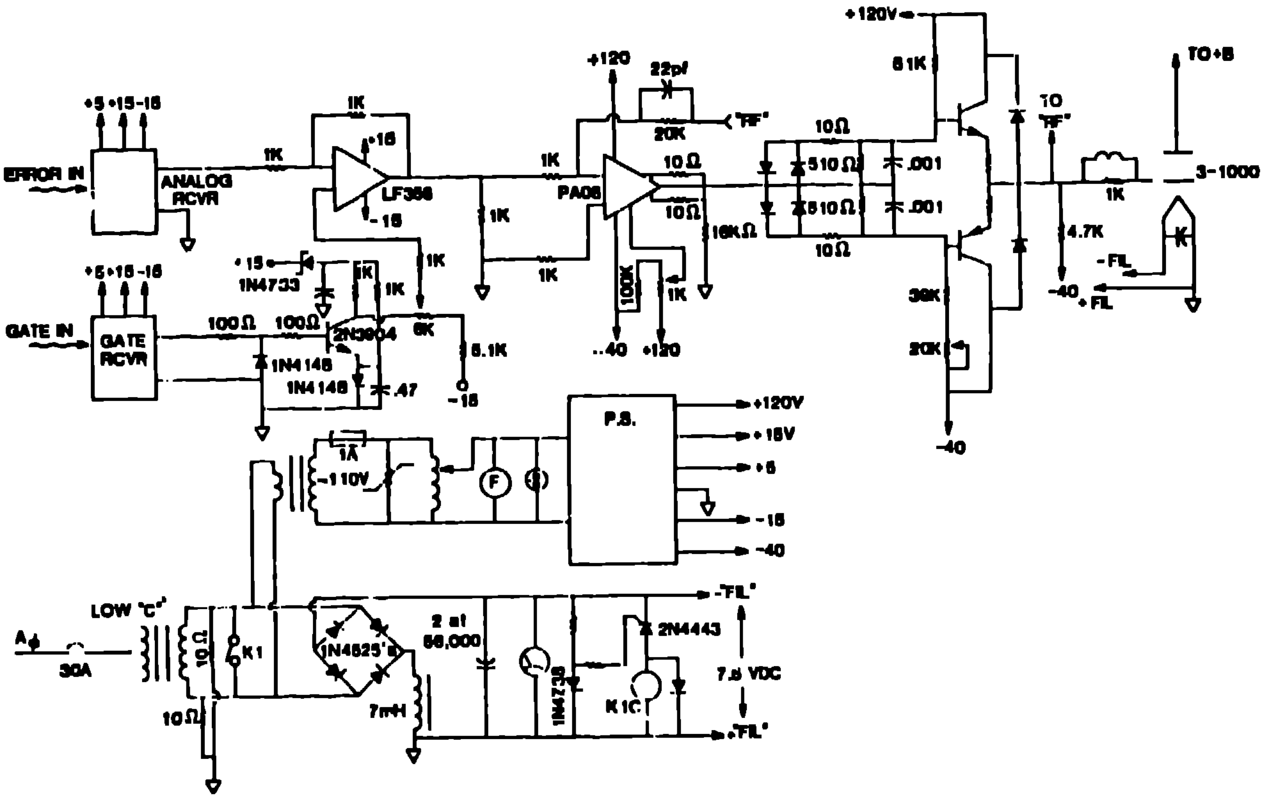


Figure 2. Internal components of hot deck.



NOTE. NO FILTER & DE-COUPLING CAPACITORS SHOWN

Figure 3. 3-1000 Floating amplifier internal components.

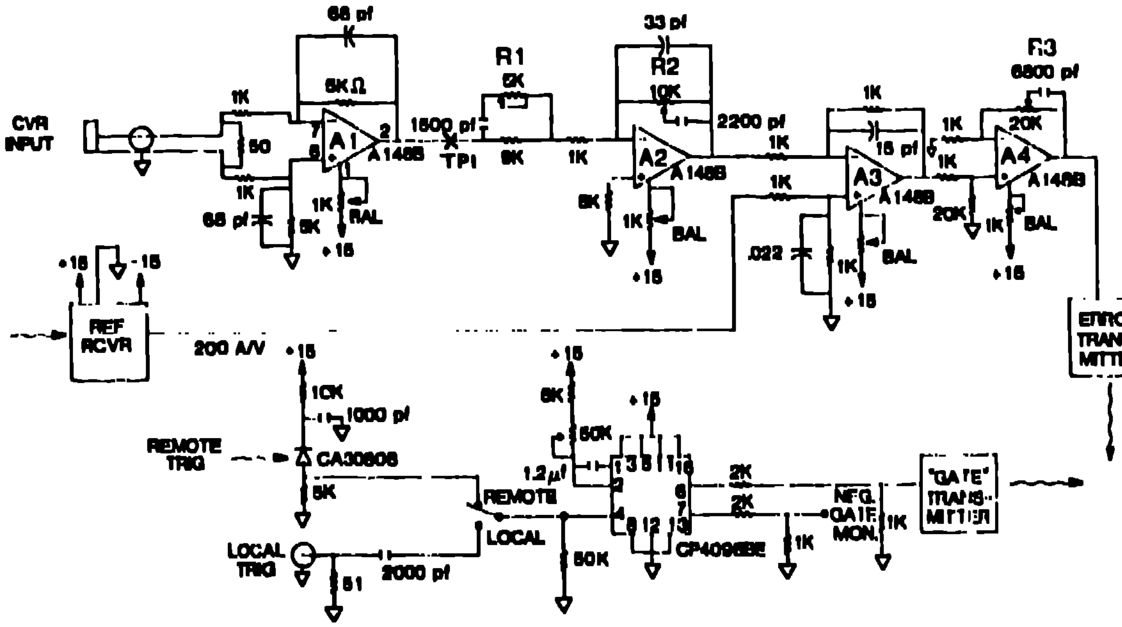
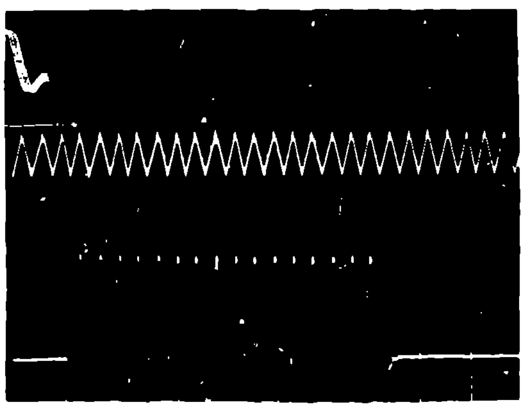
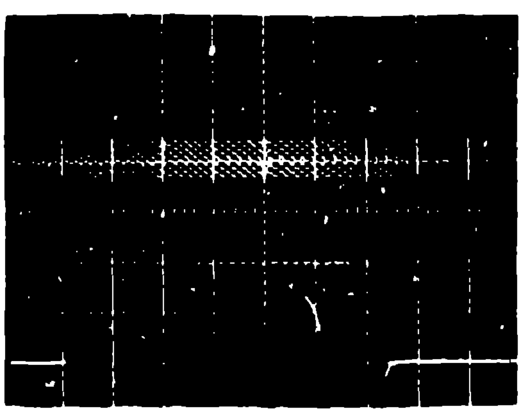


Figure 4. Error and loop compensation amplifiers.

To facilitate the required changes in compensation, various adjustments of the loop response are provided by R1, R2 and R3. Compensation on A4 (R3) was required to provide the major pole in the forward loop due to a 50-kHz parallel resonance in the VF coil very close to the uncompensated open loop 3-db bandwidth. Trace 3 shows the closed loop amplifier fidelity driving the VF coil with a 300-Hz triangle wave. An excellent match between the reference (upper trace) and the gated output (lower trace) show the achieved calibration of 200 A/V. Outstanding fidelity of sine, triangle and square wave test signals can be observed on traces 4, 5, and 6. Square pulse response detailing the risetime (~ 40 µs) of a 500-A and flat-topped 800-A pulses is depicted in traces 7 and 8. Typical waveforms for low plasma currents (~ 120 kA) can be viewed in trace 9. The upper trace is the reference voltage from the ZT-40M control room (2V/div); the lower trace, VF coil current (200 A/div). A characteristic output required of the amplifier at 400-kA plasma current is displayed by trace 10 (100 A/div).

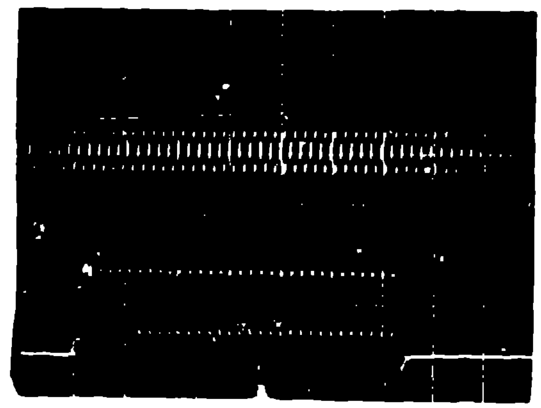


Trace 1a: 1-kHz open loop response
Top: 1 V/div Bottom: 1000 V/div



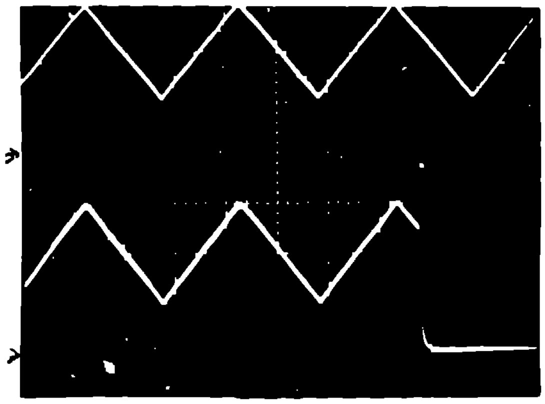
Trace 1b: 10-kHz open loop.

Trace 1c: 50-kHz open loop.

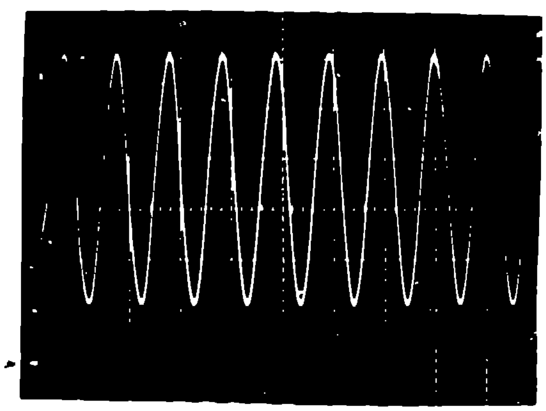


Trace 1d: 70-kHz open loop.

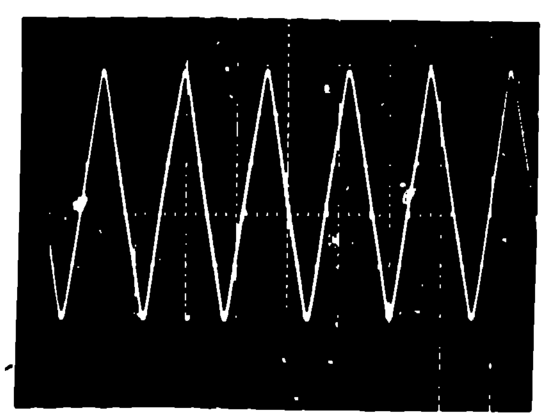
Trace 2: Initial closed loop response into VF coil
10 µs/div HORIZONTAL, 100 A/div VERTICAL



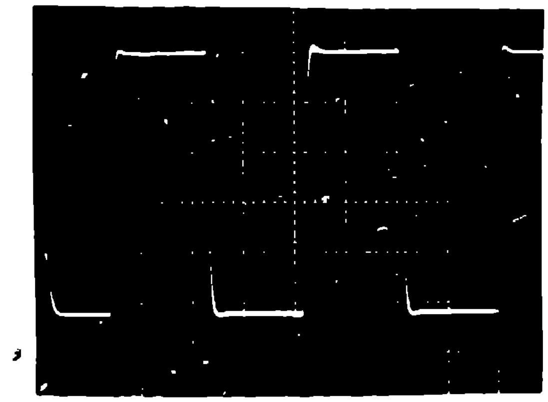
Trace 3: 300-Hz closed loop into VF Coil
T: V ref 1 V/div B: Gated output 200 A/div



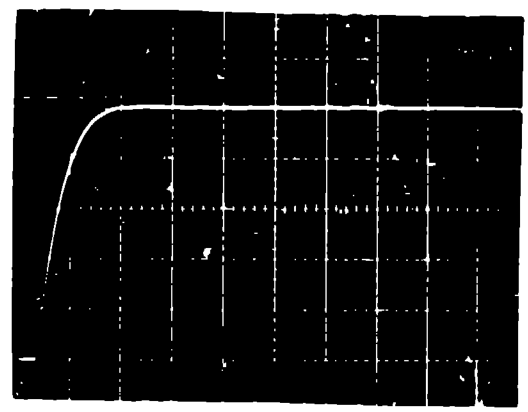
Trace 4: 2-kHz Sinewave into VF coil
100 A/div



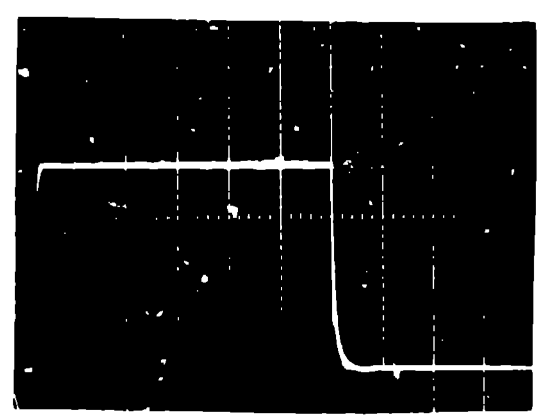
Trace 5: 1-kHz triangle into VF coil
100 A/div



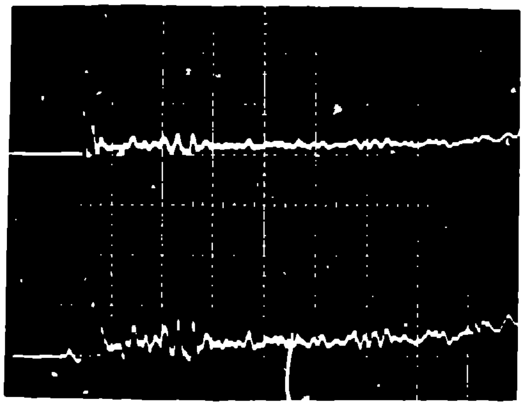
Trace 6: 500-Hz Squarewave into VF coil
100 A/div



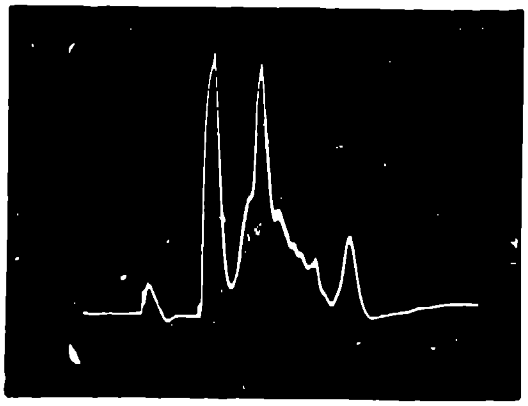
Trace 7: 500-A Square pulse to VF
50 μs/div & 100 A/div



Trace 8: 800-A Square pulse to VF
500 μs/div & 200 A/div



Trace 9: Amplifier output with 120 kA plasma
I: V ref 2 V/div B: Output 200 A/div
2 ms/div



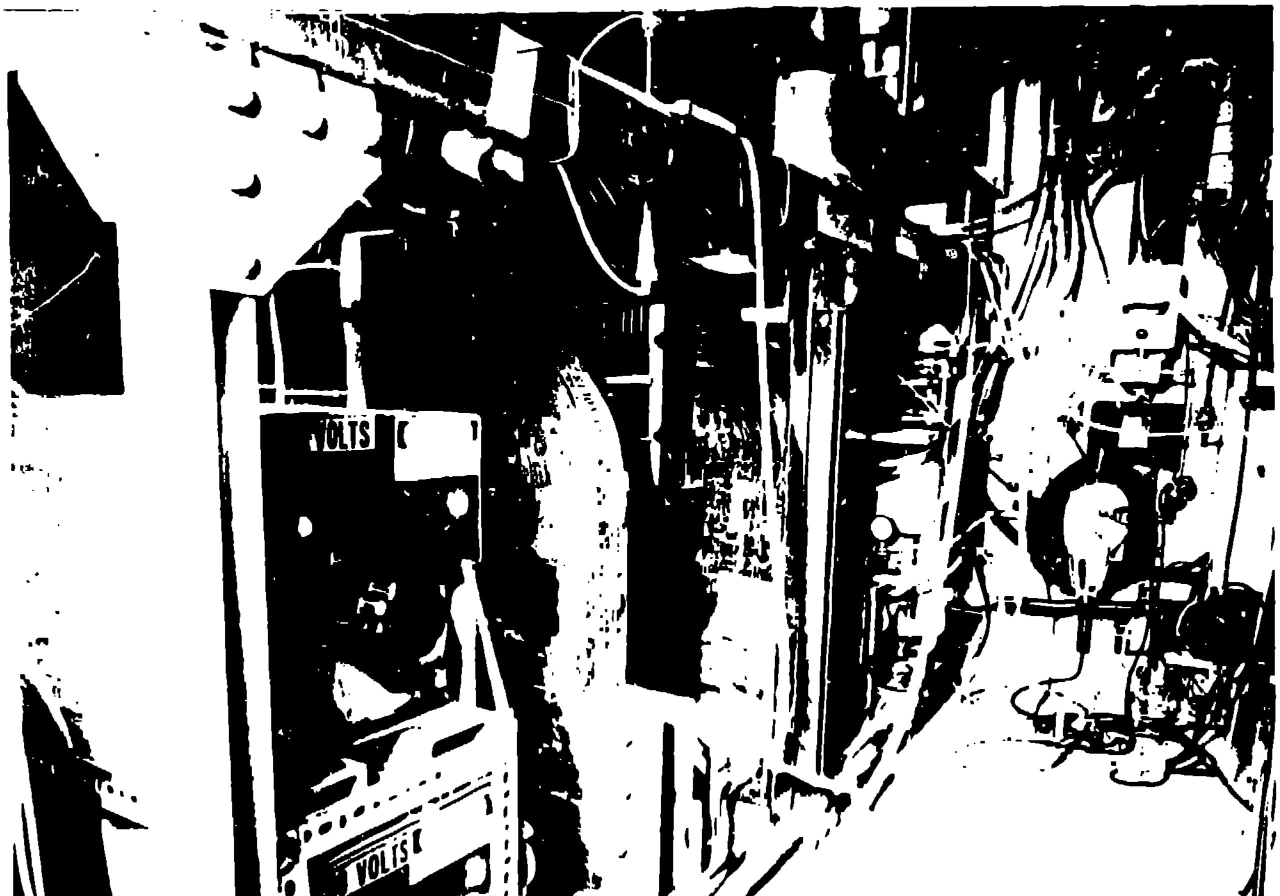
Trace 10: Amplifier output with 400-kA plasma
500 μs/div & 100 A/div

MECHANICAL DESIGN

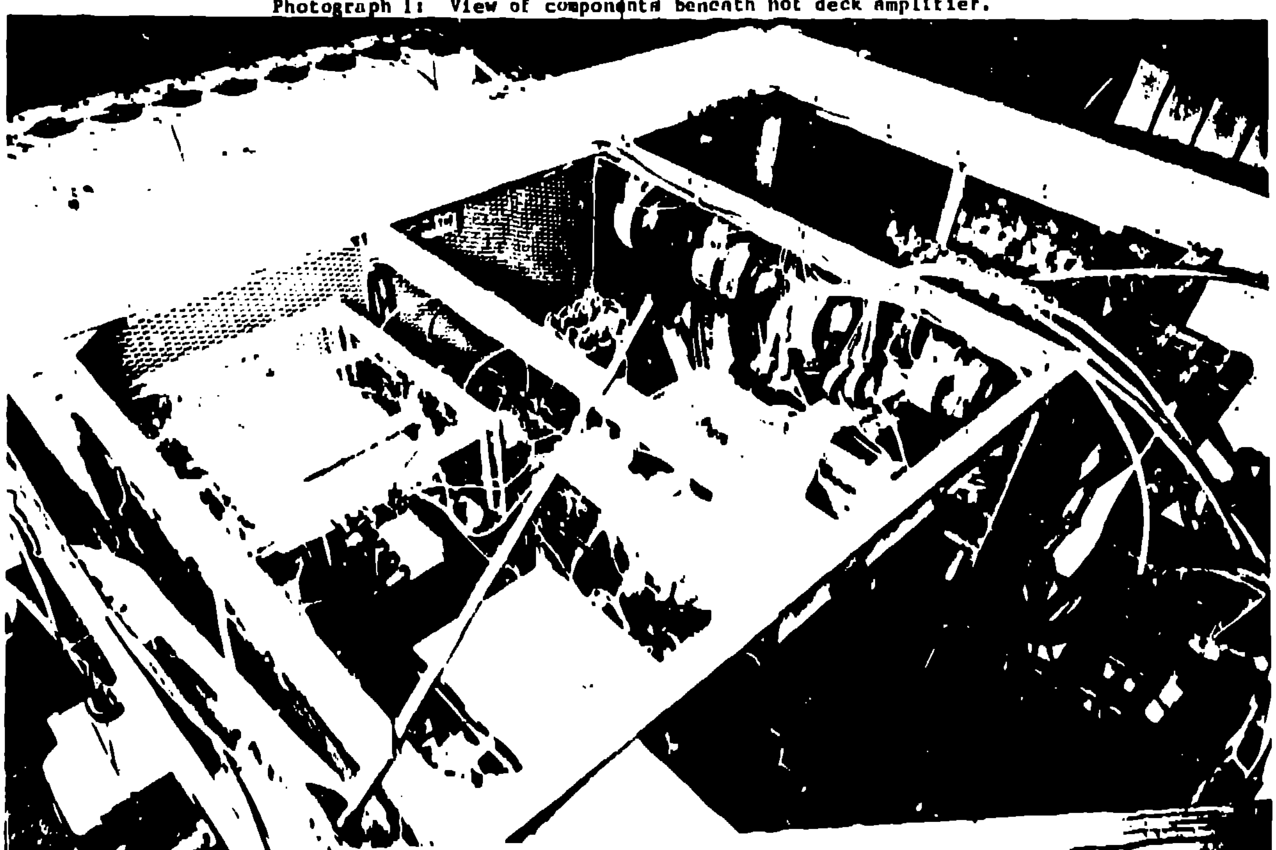
To reduce cost, maximum usage of in-house parts and home built components were used when possible. The design of the hot deck unistrut support structure and high current filament transformers can be viewed in photograph 1. An over head view of the hot deck (photo 2) gives a good indication of its size of a 4 ft. width and a 7 ft. length. The 3-1000 floating amplifier is nearest (see photo 3 also), with the larger 3CX10000A7 cathode follower next to it. The ML8618s are located at the far end, partially obscured by the cooling blowers. The drivers energy storage and charging systems are located in the rear of the hot deck. Grid D-Q components and cooling blowers next to output tubes can be seen in Photo 4.

CONCLUSION

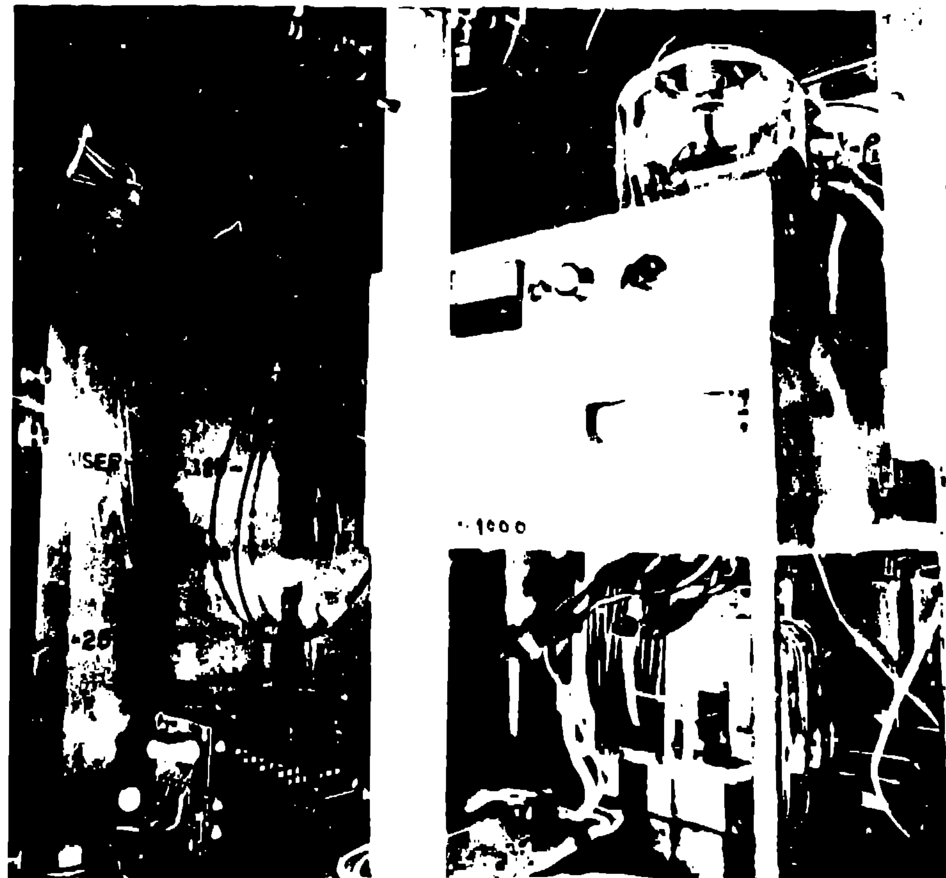
The design, construction and fabrication of the hot deck system proved to be satisfying in all respects. For our application, it proved to be an excellent design with our available in-house components. Improvements could be realized in packaging and replacement of the 3-1000 floating amplifier with a totally solid state unit. Having met all the requirements of pulse fidelity and current, we have further tested its capabilities to 1200 amperes output current. With the experience gained in the implementation of this system, a solid foundation has been laid for improved designs for the next generation system; a compact 26-MW VF amplifier (22 kV@1200 A) for the ZT-P air core reversed field pinch machine (I_θ = 10 MA/M^2).



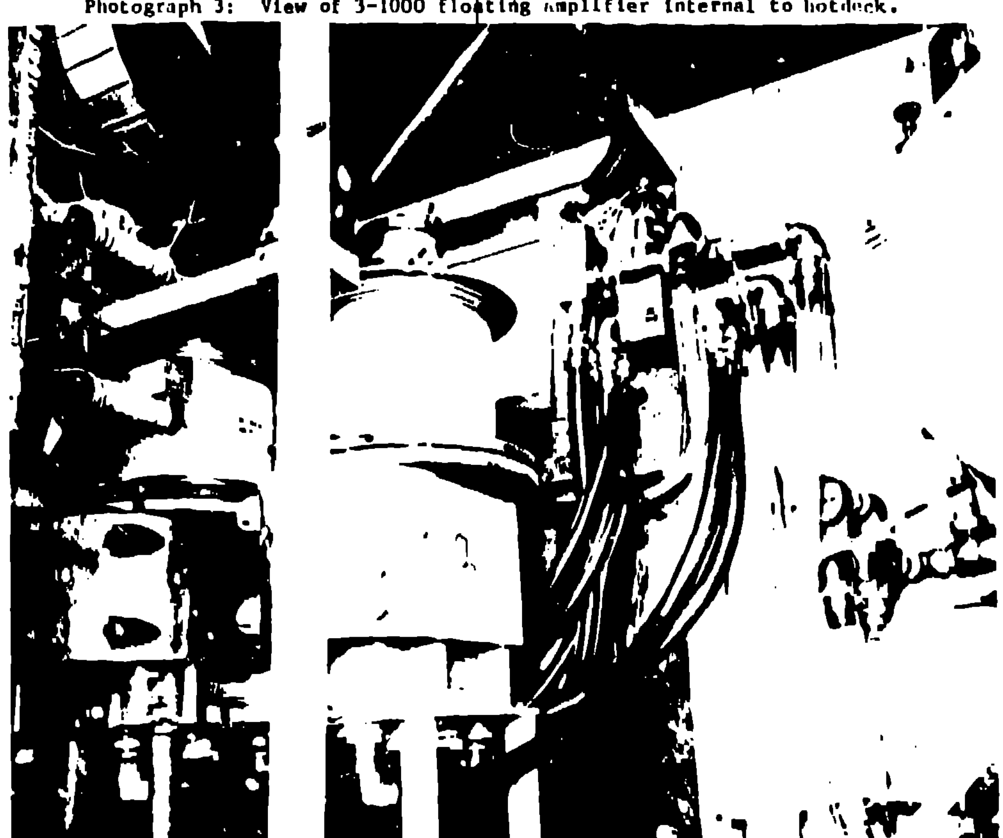
Photograph 1: View of components beneath hot deck amplifier.



Photograph 2: Overhead view of hot deck amplifier.



Photograph 3: View of 3-1000 floating amplifier internal to hotdeck.



Photograph 4: View of ML8618 magnetically beamed triode.